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Internet Accessible Remote Real-Time Laboratory For Computer Networking Curriculum

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Internet Accessible Remote Real-Time Laboratory

for Computer Networking Curriculum

(TITLE)

BY

Oyindamola Idowu

THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF

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IN THE GRADUATE SCHOOL, EASTERN ILLINOIS UNIVERSITY
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For Computer Networking Curriculum

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Abstract

Despite the availability of equipment required to teach hands-on laboratory practices in a computer networking curriculum, educators are faced with the challenge of extending such practices to students in remote locations. Distance learning has become a substantial part of the current education system, requiring institutes of learning adjusting from traditional face-to-face courses to content that can be carried out over the internet so that students can complete part or all the requirements for certain courses in an online modality. Unfortunately, traditional networking laboratories were designed with the assumption students will be physically present. This research is aimed to provide at least three feasible solutions to access a typical networking laboratory from remote locations. Specifically, this research proposes the network architecture and equipment required to provide remote access to the physical networking laboratory at Eastern Illinois University (EIU) so that students can log in to the laboratory remotely. Once implemented students will be able to securely authenticate in to the network and complete their laboratory practices. The proposed internet accessible remote laboratory, once implemented, could be adopted almost immediately to shift the face-to-face course "Networking and Advanced Data Telecommunications" TEC 5313 to an online format or at least to a minimum face-to-face requirement.

Dedication

In loving memory of my father. And specially to my mother, for her constant love, support, prayers, faith in me and daily phone calls.

Acknowledegements

Although I take the credit for this thesis and it bears my name, many people contributed to its production and completion in diverse ways and also made my graduate study an experience that I will live to always cherish.

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CHAPTER 1

Introduction

Distance learning involves delivering teaching and knowledge to people in different world locations; it is as a conscious effort to promote learning in students that are not physically present (Rajendran, Veilumuthu, & J, 2010). The beauty of distant learning lies in the fact that the source of knowledge, the instructor and the learner are separated by distance and sometimes, time. Education and training has been greatly impacted by advances in computing and communication technologies together with the increasing power of the internet and web technologies. Distance learning through remote experiments and instrument virtualization are inevitable trends that have not been acknowledged in engineering and technology education until recently (Azad, Auer, & Harward, 2012).

Better explained as a paradigm shift, educators have discovered that learning can be promoted in ways beyond direct teacher-student interaction. Media content and additional access to resources outside of the classroom hours can be used to catch better attention from today's technological savvy students. Education has been combined with entertainment to coin "edutainment" or "e-learning". In a traditional learning environment, strategically designed laboratory practices and up-to-date equipment is sufficient to effectively provide hands-on experience to students (Rajendran, Veilumuthu, & J, 2010). However, student enrollment is greatly hindered because educators may be unable to design classroom and laboratory meetings to fit into each potential student's plan of place and time. As a result, a large percentage of laboratory equipment lies idle for the most part of usable life cycle.

Research has been carried out on internet accessible laboratories in electronic circuit design, robotics, medicine, physics, pilot training, and chemical analysis. Yet, little has been done in the development of internet accessible laboratories to corroborate teaching laboratory practices in telecommunications. A tangible and worthy element of research, internet accessible remote laboratories in telecommunication is more than another educational resource, it a tool for promoting habitual practice in students using what fascinates today's student to develop the student's understanding and mastery of the subject

Laboratory experience makes it easier for students to understand theories and concepts learned in class. A complete curriculum for networking requires both theoretical and practical sessions in order to prepare the student for real life scenario and improve the student's competencies for the job market (Yoo and Horis 2004). Tang, Draper and Xu (2008) stressed that a traditional laboratory offers limitations in an academic environment where students may register for distance learning courses that require a laboratory component.

When a university decides to change traditional face-to-face courses that are mostly theoretical to an online modality, the transition is typically smooth. However, the challenges are complex for courses with high technological content and practical hands-on laboratory requirements. Networking skills are properly developed with diligent practice which typically requires working outside classroom hours. It is expected that a university that is able to provide access to such equipment 24/7 from any location will be highly desirable and might be perceived as more student friendly. A typical online networking laboratory must be designed with the following characteristics:

- Strong student interaction with the networking equipment
- High degree of availability
- Secure remote access
- Mimic the real physical interaction with equipment
- Minimal participation of an instructor or teaching assistant

The School of Technology at Eastern Illinois University (EIU) offers Computer Technology as a concentration for Master of Science Program with the aim of producing graduates who are professionally competent and highly employable (School of technology n.d.) . In addition to two undergraduate courses in routing and switching, two graduate level networking courses are also offered in the Master's program; "Networking and Advanced Data Telecommunications" TEC 5313; and "Network Security" TEC 5353. These graduate courses are aimed to prepare students for careers in Network Adminstration as well as Network Security Management.

According to Sakar (2006), "students who take only theoretical courses tend to find the subject too technical and boring while practical activities help students to understand concepts effectively". To this end networking courses at EIU includes laboratory practices such as:

- Building a Local Area Network
- Knowing the Router Operating System
- Static Routing Troubleshooting LAN and WAN
- Dynamic Routing using EIGRP and OSPF
- Access-lists as basic firewalls
- NAT and PAT configuration

- Creating De-militarized zones and VPN configurations

Networking laboratories in most academic institutions have been designed assuming that the student will be physically present. According to Zetino (2011), "The Telecommunications Laboratory at EIU has state-of-art devices capable of providing students with needed practicalbackground to kick-start a career in network administration". However, the current design of the laboratory requires students to be physically present to take advantage of this facility.

Statement of the problem

The present design of Telecommunications laboratory requires students to be physically present to take practical sessions for networking classes. In spite of the availability of numerous and advanced equipment, distance learners are unable to take hands-on networking courses Even traditional students who are physically present also face certain limitations.

Traditional students as well as distance learners intending to take networking classes at EIU are faced with at least one of the following problems

- Zero accessibility of the networking laboratory facilities from remote locations on campus (i.e. dormitories or other facilities) or off-campus.
- Time limitation to weekly class meetings and fixed laboratory open hours all of which requires a graduate assistant to ensure that students achieve the desired results without causing any damage to laboratory equipment. For on-campus students, open laboratory hours may not fit into the student's schedule as it may clash with the student's other class or job schedule.

- Physical space limitation; only about ten students can have full access to the laboratory facilities at EIU at a given point in time.

Statement of Purpose

The intent of this research is to find feasible solutions to the problem of limited use and low level of accessibility of existing networking equipment in the School of Technlogy at Eastern Illinois University. The goal is to increase the level of availability and flexibility of networking courses and laboratory practices for the Master of Science curriculum such that at least the course TEC 5313; Networking and Advanced Data Telecommunications can be taught in an online modality.

Using a personal computer and internet access from any world location, students will be able to authenticate into a virtual laboratory or the real laboratory and carry out certain practices using provided laboratory guides. Remote authentication will reduce the visits to the laboratory each semester and at the same time allow students to do laboratory assignments at their own pace and convenience while maximizing resources

Significance of the Study

The outcome of this research will provide viable alternatives to ensure that a networking course at EIU can be taught to students at any world location with a personal computer and internet access. Guided with adequate instructions, easy to use laboratory guides and multimedia technologies, students should be able to access the laboratory 24/7. This will potentially reduce visits to the laboratory facilities by the local students to the minimum while distant learners might not have to visit the laboratory at all.

Objectives

This research intends to achieve the following objectives and outcomes:

1. To comprehensively research how to increase the level of availability and accessibiility of the networking laboratory.
2. To reduce the number of physical meetings for TEC 5313 students and also lay a foundation for reducing the number of physical meeting for other networking courses.
3. To enhance the use of laboratory equipment remotely
4. Propose viable topology design changes to the telecommunications laboratory that will allow students to log in and perform laboratory practices remotely.
5. Recommend security implementations in order to protect laboratory facilities the students and unauthorized persons.

Delimitations of the Study

This research might not completely eliminate some laboratory practices that require strictly hands-on activities, although a combination of solutions can be applied to overcome the challenge. This research is not expected to provide immediate access to the existing School of Technology laboratory facility; it will only serve as a theoretical proposal for future implementations. In like manner, this research does not address the fact that students will not be able to build or change laboratory physical topologies remotely; still the instructor must change topology, if necessary, before each laboratory practice in order to access the facilities properly and remotely. This research will be limited to provide online laboratory access to just one course initially: TEC 5313 "Networking and Advanced Data Telecommunications." The same concepts however can be applied in the future for other potential online courses.

CHAPTER 2

Literature Review

In the previous chapter, the need for accessing the Telecommunications laboratory at Eastern Illinois University from remote locations was discussed. This chapter will provide background information and theoretical justification for flexible networking laboratory practices and remote access to laboratories for the computer networking curriculum.

Distance Education

Distance education involves delivering teachings to students, especially those that are not physically present. From many types of learning, distance education gives adults the opportunity to improve on their career and enhance their skills while earning (Iqbal, Kousar & Ajmal 2011). The fast progress in technology requires engineers employed in the industry to constantly refresh and update their professional knowledge but time and distance have always been restrictions from getting an additional qualification while working (Rojko, Zurcher, Hercog, & Stebler, 2011).

According to Chaney, Eddy, et al (2007), distance education has helped to increase access to courses and at the same time increase revenue for academic institutions. Khan (2003) explained that distance education offers a modernized delivery channel, expanding the traditional educational system. Research has shown that students today are more likely to use new tools and technologies to improve their understanding of a subject matter.

Although difficult to achieve in distance education, laboratory practices cannot be ignored or replaced; Lahoud and Krichen (2010) explained that since the inception of distance learning, teaching technical courses online has been a challenge to educational institutions. .The need for laboratory practices is especially important in science, engineering and technology. Gregg (2008) stressed that laboratory practice is as important to a computer security specialist as it is to a chemist or a biologist. Gregg (2008) went further to explain that "although there are manuals that explain how different networking devices work in isolation or within a simple network architecture, but these manuals are inadequate to explain how networking devices will behave when they are part of a complex network. Only real experience with the equipment is able to closely replicate real-life situations and help the learner to develop troubleshooting skills."

Internet accessible laboratories in electrical engineering for basic courses like electricity and electronics have been greatly researched and developed. Online telecommunication laboratories have not been successfully implemented yet in the US. Jabbour, Haydamous, Kazan, & Hayek (2006) stressed that "very few remote internetworking laboratories have been implementation with several drawbacks". In recent years, internet accessible telecommunication laboratories are being researched theoretically with increased technicality and enthusiasm resulting in more published papers on the subject but little has been done to propose a full working implemented solution. Scholars are now interested in the development of remote computer network laboratories, virtual laboratories and powerful network simulation programs that closely mimic the operation of corporate computer networks (Lawson & Stackpole 2006).

Evolution of Learning Styles

Education had been centered on direct teaching in a classroom environment for ages. However, educators have realized that including entertainment in the learning process is a more attractive to the student. The traditional method in which the student listen and only learn from what they were told by the teacher was referred to as auditory learning and was mostly prevalent in countries like India, China and most parts of Africa (Rajendran, Veilumuthu, & J 2010). Ozvoldova & Schauer (2012) stated that "most of the class time involves the teacher lecturing the students and laboratory sessions were bound to the time schedule of the lectures and as a result students were learning mechanically, memorizing facts without gaining any deep understanding of the subject". The students lacked in-depth knowledge of the subject and the students understanding was limited by the level of knowledge of teacher (Rajendran, Veilumuthu, & J, 2010)

Auditory learning was improved upon and visual learning was developed to include the use of pictures, charts, PowerPoint presentation and even blackboard illustrations. Students were able to picture what the system will look like in actual sense, but they were still ignorant of the details of the system's operation and behavior (Rajendran, Veilumuthu, & J 2010).

Educators then began to combine auditory and visual learning with multimedia components like 2D and 3D videos. This was referred to as Computer Based Teaching CBT. With this huge improvement, students were able see what the system looks like and how it works. Only that the student was unable to experiment and created different scenarios with systems or guess the likely behavior of the system in situations beyond what the curriculum covered (Rajendran, Veilumuthu, & J, 2010), (Ozvoldova & Schauer, 2012).

Eventually learning evolved to become kinesthetic to involve learning by doing; students were able to perform experiments and observe the system behavior under changing variables. This helped to improve logical thinking and cognitive knowledge.

Cost as a constraint in Traditional Laboratories

Although kinesthetic learning helped students to learn by doing and also experiment with "what if" scenarios, it was not without major drawbacks. Some of the disadvantages of kinesthetic included:

- Students may damage expensive equipment ignorantly
- Students may get injured if performing "test operations" with certain substances like chemical without supervision
- Student can completely shut down a network just by testing new protocol or new concepts ignorantly
- Students have to be physically present to take the laboratory practices
- Cost of constant upgrades to laboratory equipment which requires funding and is a constraint on limited resources.

For instance, as of today the laboratory equipment at EIU is up-to-date and adequate to teach practices in networking courses. However, in a couple of months, an upgrade it might be required at an additional cost. This is a continuous trend in technology as old equipment became obsolete and new ones will be required to teach new concepts. Yoo & Horis (2004) indicated that, having a networking laboratory with proper hardware facilities has different challenges with funding for constant hardware upgrade being the most prevalent. This research will also involve using virtualization to present some laboratory practices to students and as a result, reduce the cost of purchasing additional equipment to teach new concepts

The Role of Simulation, Virtual Laboratories and Remote Laboratories

Different techniques and methods are being used to provide a different degree of learning experience to distance learners and at the same time reduce the cost of constant upgrades. This includes demonstration videos, remote access to physical laboratories, simulation software, and virtual laboratories by institutions with the aim of providing a level of satisfaction similar to face-to-face experience.

Virtual laboratories and simulations came to the rescue of kinesthetic learning and provided a safe way of learning by doing. With virtual laboratory, the student can follow his/her imagination and explore a series of "what if" scenarios by changing input and learning from the different response of the system (Rajendran, Veilumuthu, & J, 2010).

Simulations

According to documented history, the use of simulation precedes the use of computers. Simulation is the process of imitating the behavior of a system; either physical or abstract in order to observe how the original system is likely to behave in different situations, event or circumstance. Chorafas (1965) described a simulation as a working analogy of a system that can help the designer predicts the likely reaction of the system. This eradicates the need for a physical device while allowing designers to pre-decide on how to optimize the characteristics of a system.

Simulations are arguably multifaceted and cuts across multiple disciplines and different aspects of each industry, be it computing, scientific research, quality, military, safety, education and training, manufacturing floor or in the office (Damassa & Sitko, 2010). (Rorabaugh, 2004) advocates that modern communication systems and devices would not have been possible without simulation which has helped tremendously in the mass production of devices such as cell phones. Simulations make it possible to exhaustively test and hone the design of otherwise complex devices. It will be unwise to mass-produce a device that has not been extensively tested. Even with simulation, it is impossible to have tested a device under every possible operating conditions, but the complexity and tendencies of failure would have been reduced drastically (Chorafas 1965).

Computer simulations date back to World War II (Nance & Sargent, 2002). Computer simulations have been used extensively in networking as a technique in which programs that mimics the behavior of a network are used to observe the interaction of different network components. Network simulations make it possible to observe the behavior of a network, its application, services and various attributes of the environment that can be modified or controlled to assess the network's behavior under different conditions (Damassa & Sitko, 2010).. It is important to note that the actual network does not need to be present because the simulator is a computer program that was designed to imitate a computer network for performance analysis.

Network simulators can also be customized to serve specific learning purposes in laboratory practices thereby creating a virtual laboratory. These simulators support various networking protocols such as TCP, UDP, IP, and wireless standards. Most commercially available network simulators are Graphic User Interface (GUI) driven while some are command line-based. Some examples include ns2/ns3, OPNET, NetSim, Packet Tracer and Virtual Laboratory packages. When compared to the time required to create a complete test network and the associated cost of the required devices, simulators are faster and cheaper. They also make it easier for researchers to test how a new protocol will behave in an existing network.

Popular Network Simulators

ns-2/ns-3: Although ns-3 is a newer development, ns-2 and ns-3 are discrete-event network simulator developed under through research grants and activities and targeted primarily for research and educational use, a project that started in 1996. They are free and licensed under the GNU GPLv2 license and publicly available for research and development. The goal of the project was to develop a preferred, open simulation environment for networking research and encourage community contribution, peer review, and validation of the software. The ns-3 simulation core supports research on both IP and non-IP-based networks (ns-3 n.d.) (ns simulator 2013)

Although most users focus on wireless/IP simulations like Wi-Fi or WiMAX for layers 1 and 2, ns-2 is often criticized because it is complex and difficult to model with. It also lacks a GUI and as a result, the user has to learn the scripting language and modeling techniques. Ns-3 is criticized for inconsistent results and lack of backward compatibility with ns-2 (ns simulator, 2013).

OPNET: OPNET stands for Optimized Engineering Tools, a graduate project in networking at MIT by Alain Cohen, his brother Marc Cohen, and their classmate Steven Baraniuk. The networking soft was later commercialized in 1986 and the company OPNET Technologies, Inc. was born in 1986 (Erwin, 2011). This simulation tool provides performance analysis for computer networks and applications. OPNET software can help academic institutions add a new approach to the textbook teaching of theoretical courses when integrated into the curriculum.

According to Erwin (2011), "OPNET, is a network simulation tool with features and tool set including a packet format that defines protocols, a node model for specifying network component interface, a process model for the abstraction of behavior of a particular network component, a project window for defining the topology of the network and various linkages, and a simulation window that is able to capture or show the results of network simulation."

In contrast to ns-2 or ns-3, OPNET has an easy to use GUI, offers solutions for network performance management, application performance management, and network R&D. The University of Michigan uses OPNET to investigate the various protocols, algorithms and hardware design for future army communication systems from a low energy perspective (Academic OPNET research and educational projects n.d.)

NetSim: NetSim Network Simulator is an application used to simulate Cisco Systems' networking hardware and software. It was designed specifically to the learning of Cisco IOS command structure. NetSim software includes a comprehensive laboratory menu containing of lessons and laboratory practices for routing protocols, Cisco devices, switching and topological design (NetSim Network Simulator, 2013).

Packet Tracer: According to Cisco packet tracer (2010), it is a powerful network simulation and learning environment that allows students to experiment with network behavior and ask "what if" questions. It is a hi-tech supplement to physical equipment that allows students to create and configure networks with an unlimited number of devices while encouraging practice, discovery, and troubleshooting. Studies carried out on the effectiveness of Packet Tracer in teaching networking practices demonstrated that packet tracer can be used for both instructional and assessment purposes (Frezzo, Behrens, Misleyy, West, & DiCerbo, 2009).

In a report by Maj & Veal (2010), Packet Tracer is used extensively in the Cisco Networking Academy Program (CNAP) although it does not provide practical hands-on skills. Students have access to simulated device Internetworking Operating System (IOS) such as routers, switches, firewalls, servers, personal computers, multi-user connections and different cabling options. Packet tracer is designed to be easy to use and to give students 21st century networking skills, including decision making, critical thinking, and problem solving. Packet tracer is available for free download on www.cisco.com and involves simple account creation steps.

According to Maj & Veal (2010), Packet Tracer is a cost-effective tool that allows students to build, configure and test simulated networks while offering both logical network topology and the physical view of equipment. Using Packet tracer will offer students the flexibility of designing network topologies while carrying out assignments in remote locations. Inquisitive students will also be able to use the simulation software to design more complicated topologies out of curiosity while improving proficiency and skills.

Virtual Laboratories

Another interesting solution is virtual laboratories which are similar to simulation software only that they are more specialized and less flexible. A wise man once stated that a picture is worth a thousand words. Virtual laboratories however take this saying a step further by using not just pictures but also using animations, interactive and specialized simulations to enable students to visualize and interact with a "supposed" system. The learning process is engaging and requires active input from the user resulting in a positive experience (Huang, 2004).

Virtual laboratories offer low-cost access to devices hosting virtualized network topologies. This way, it is possible to have a "non-physical" networking laboratory. Virtual laboratories are in use at North Carolina State University to deliver a dedicated computing environment to users for a limited time (Fapeeler, 2008). George Mason University uses virtual laboratories as a learning resource for faculty and students to provide access to specialized software in a safe environment without having to purchase or install the software on their personal device.

Use of Simulations and Virtual Laboratories in Teaching

The idea of using simulation in teaching is an exciting and proven teaching tool for illustrating rather complex and changing situations. Simulators can be honed to be less complex than the situations or systems that they represent. The beauty of simulation in teaching is that the learner takes certain actions and the simulator reacts immediately (Deniz, Bulancak, & Ozcan, 2003). The reaction of the simulator acts as feedback to the learner who is able to adjust or rescind his action. Every decision or step that the learner takes affects the outcome or output of the simulation. According to (Damassa & Sitko,

2010) simulation technologies have proven to be valuable tools for effective competency-based education.

The department of Computer Science, George Mason University produced its own network simulator called Network workbench in order to address the challenges the program faced in teaching introductory networking courses. Network Workbench abstracted away the unimportant details of networking projects making it faster and easier for students to understand the concepts (Pullen, 2002).

Simulation Summary

Organizations and academic institutions have extensively used simulation for training and testing systems in order to anticipate the likely behavior of such systems under varying circumstances. Compared to other applications such as manufacturing and training, simulations have also been used extensively in education.

Educators and researchers have however concluded that although simulations can provide 'close-to-reality' experience, it does not provide the problem-solving realism of actual hands-on experience with the equipment (Deniz, Bulancak, & Ozcan, 2003) and it does not provide an exact feeling of the actual equipment or totally mimic the problem as it likely to occur in reality (Cooper, Donnelly, & Ferreira, 2002).

It is also believed that students who were trained only with simulators and virtual laboratories tend to be timid when they are exposed to the real equipment especially on their first job. It is therefore imperative that in addition to using simulation and virtual laboratories, students be exposed the physical equipment to touch and feel the reality of it. This will help students to better understand what they are doing when working with simulators.

Remote Access to Physical Laboratory

Remote surgeries, real-time ocean floor experiments, and mini-blogs from Mars; the internet and capabilities of personal computers have not only changed the way we engage in science and engineering, it has also revolutionized collaborative research (Albon & Cancilla, 2012).

A Remote laboratory as defined by Lloret, Jimenez, Diaz, & Lloret (2008), "is a group of physical devices that can be driven and controlled remotely, simultaneously or not, by many users, using the same type of interface." This means that unlike simulations, physical equipment is involved although they are accessed from a remote location (Jabbour, Haydamous, Kazan, & Hayek, 2006).

Over the years, internet-based remote access to laboratories has gained popularity due to the power of personal computers and more bandwidth availability on the internet (Border 2007). Unlike in previous years, remote laboratories can now provide shared access to equipment (Lahoud and Krichen 2010), allowing configuration, troubleshooting and maintenance practices by the learner making it cheaper for universities and organizations to offer education and training to multiple people in dispersed locations.

Although distance learning started in the mid-1800s, the first remote access to a computer was carried out in the 1940s using a modem and a dedicated telephone line which was quite expensive. The development of remote access laboratories have grown exponentially in the last decade, especially in engineering and computer science disciplines (Hashemian & Pearson, 2012). In the early 1990s, the first remotely shared control system laboratory was proposed at the American Society of Enigineering Education (ASEE) Frontiers in Education Conference (You, 2012). Truly advanced and cost effective remote access laboratories were first developed in 1994 in Australia and Switzerland to enable students do experiments at their own pace, time and location.

Many works have followed resulting in the development of remote laboratories in mostly electronics and robotics using LabVIEW or other platforms. Examples include; a remotely accessible real time manufacturing and automation laboratory (Gurocak, 2000); ;a remotely controlled four-axis robot (Cooney & Shiver, 2001); A labVIEW-based Remote Laboratory: Architecture and Implementation, a labVIEW-based remote wet process control laboratory developed for manufacturing and automation courses at Morehead State University (You, 2012); Remote laboratory with re-configurable internal debugging interface (Hashemian & Pearson, 2012)

LabVIEW's architecture makes the integration of laboratory environment with remote manipulation easy by moving the user interface away from the physical setup. The local computer serves as a web/control server to which remote clients can connect although there can be only one active remote user at a time while other users observe (You, 2012). Remote users gain access to the experiment on a first-come first-served basis maintaining a queue

Some of the existing remote laboratories are shared between different universities for the purpose of maximizing resources and collaborative research. Among these are:

1. labshare, a project developed by Universities in the USA, Sydney and Australia (Hashemian & Pearson, 2012)
2. EDIPE (E-Learning Distance Interactive Practical Education) project developed by thirteen partners including from eleven countries in Europe University of Maribor for power engineering and motion control remote labratories. This

project is now used to offer eighteen courses with remote experiments successfully (Rojko, et all., 2012)

3. iLab was started as a result of Prof. Jesus del Alamo work at MIT in 1998; he designed the Microelectrnics WebLab for semicondudtor laboratory practices. Following that, remote laboratories were designed for other courses leading to the development of a standardized architecture; iLab Shared Architecture in 2002.

Today, iLab consists of partners and a network of universities sharing equipment from the Massachusetts Institute of Technology, USA. This includes Northwestern University, Illinois USA; the University of Queensland, in Brisbane Australia; the University of Dar es Salaam, Tanzania; the Makarere University, Uganda; the Obafemi Awolowo University, Nigeria; enabling partners that lack laboratory facilities to utilize resources at MIT for experiments in electrical engineering (Mwikirize, et al., 2012).

Remote access to networking laboratories according to Liu, Marti and Zhao (2001), represents an aggressive approach to quality instruction of networking students in higher education. Liu et al (2001) stated that is difficult for instructors to teach all concepts of networking during limited lecture hours and for students to understand the broad subject in traditional classes alone. Additional hours are needed for students to have adequate hands-on experience with networking devices. Internet-based remote access will give students the added benefits of self-pace and interactivity from the comfort of their homes, on campus or from their offices.

Remote laboratories have helped to increase accessibility of networking laboratories and to reduce the cost of multiple equipment and constant upgrades. This was indicated in a study by Lahoud and Krichen (2010) which explained that although remote laboratories were primarily designed for individual learners, they can be used for collaborative work among multiple learners to mimic a situation where two or more people manage a physical network. Some remote laboratories are used to completely replace laboratory exercise and at the same time combine both local and remote experiments (Rojko, Ziircher, Hercog, & Stebler, 2012)

Effectiveness of Remote Access Laboratories

According to Rojko, Ziircher, Hercog, & Stebler (2012), the level of development and research that remote laboratories are experiencing makes it imperative to assess the degree to which remote laboratories can replace hands-on experiments. Attempts have been made on the part of researchers and scholars in different academic disciplines to evaluate the learning outcomes in the use of remote laboratories using different criteria such as the user's background/discipline, the user's level of comfort using the remote laboratory, usability, accessibility and speed.

Different researchers have reached different but similar conclusions showing positive attitudes from users, level of satisfaction and leaning outcomes similar to hands-on experiments (Rojko, Ziircher, Hercog, & Stebler, 2012). Lahoud and Krichen (2010) argued that the effectiveness of remote networking practices depends on the computing capabilities of the student. Yoo and Hovis (2004), Sloan (2002) and Sloan and Schlindwein (2003) have all studied and presented methods of implementing remote access to network laboratories effectively in order to obtain tangible learning outcomes. The result of a survey conducted at the University of Maribor, Slovenia shows that most users appreciate the space and time independence although some users reported that they would prefer the hands-on experience. Overall, 90% of learning goals were met (Rojko, Ziircher, Hercog, & Stebler, 2012).

However, there are few studies that show that a high percentage of traditional students are not comfortable with the current trend towards replacing hands-on experiments with remote laboratories although they appreciate the use of remote laboratories in addition to hands-on experiments. In a study, Lahoud and Krichen (2010) reported that students prefered simulations more than remote and traditional laboratories; traditional laboratories being the least desirable and accessibility being the most important factor indicated by the students. Simulations, however may not be able to perfectly imitate all capabilities of networking equipment. Lahoud and Krichen (2010) also stated that computer networking and networking laboratories will continue to evolve towards remote and virtual networking interfaces.

Remote Laboratories in the Industry

Although remote laboratories are thriving in university education in recent years, it is surprising that they are not experiencing the same level of research and development in non-formal education by companies in the training industry. Statistical data shows that 38% of European employers train their employees using traditional face-to-face methods (EUROSTAT, n.d.). Except for companies like Cisco Systems and IBM, little has been documented on the percentage of employers in the USA that train their employees either remotely or traditionally, despite the fact the profesionals in information technology will oftentimes need to update their knowledge in order to remain competitive in the face of new technologies (Rojko, Ziircher, Hercog, & Stebler, 2012).

Many reasons have been stated why employees do not get additional degree or training while working even if the training is funded by the organiazation. The reasons includes traimning time clashing with work time, the distance they need to travel to get the trainning, family responsibilities, non availability of such training at "convenient hours" (Rojko, Ziircher, Hercog, & Stebler, 2012). All these stated reasons can be addressed with distance learning or remote training.

There is truly no established reason why remote laboratories have not been largely deployed outside educational institutions. However, some researchers have stated very logical reasons. Rojko et all (2012) argued that the major cause for the lack of usage of distance learning in industry is due to the fact that remote laboratories are non-standardized solution with non-industrialized hardware and that older employees do not posses the necessary computer skills required to operate remote laboratories.

Aided by advances in computing technologies and availability of more bandwidth on the internet, online laboratories have enjoyed extensive development and numerous scholars have carried out research in different areas to further develop or evaluate the success of online laboratories as a tangible element for distance learning. Based on literature and studies presented in this chapter, it can be deduced that computer simulations and virtual laboratories have been around much longer and have been developed to cut across multiple disciplines to allow students to test "what if" scenarios. Remte laboratories however provide results that closely mimic real interaction with real equipment; is still being intensively researched in multiple disciplines and is likely to be widely deployed in institutes of learning even research in remote laboratories continue to grow.

Chapter 3

Design Methodology

This chapter presents the details of the approaches that can be implemented in order to offer the course TEC 5313 in an online format. This chapter also gives the foundation for teaching similar technical courses in the School of Technology at EIU in an online modality using one or more of the methods presented in this research.

Overview of Current Laboratory Design

In previous research work, (Zetino, 2011) designed the topology which is currently in place at the Telecommunications laboratory at EIU with the objective of improving utilization of currently available equipment. Based on this objective, Zetino (2011) redesigned the laboratory as shown in Figure 1. In most of the laboratory practices in TEC 5313, students use the fixed topology labeled "Internal Network" (The right part of Figure 1) where they need to perform different tasks based on the objectives of the laboratory practice.

The telecommunications laboratory at EIU has been designed to demonstrate to students how theoretical networking concepts can be applied in a real life scenario. Laboratory practices have been carefully designed to meet this goal in through thorough design.

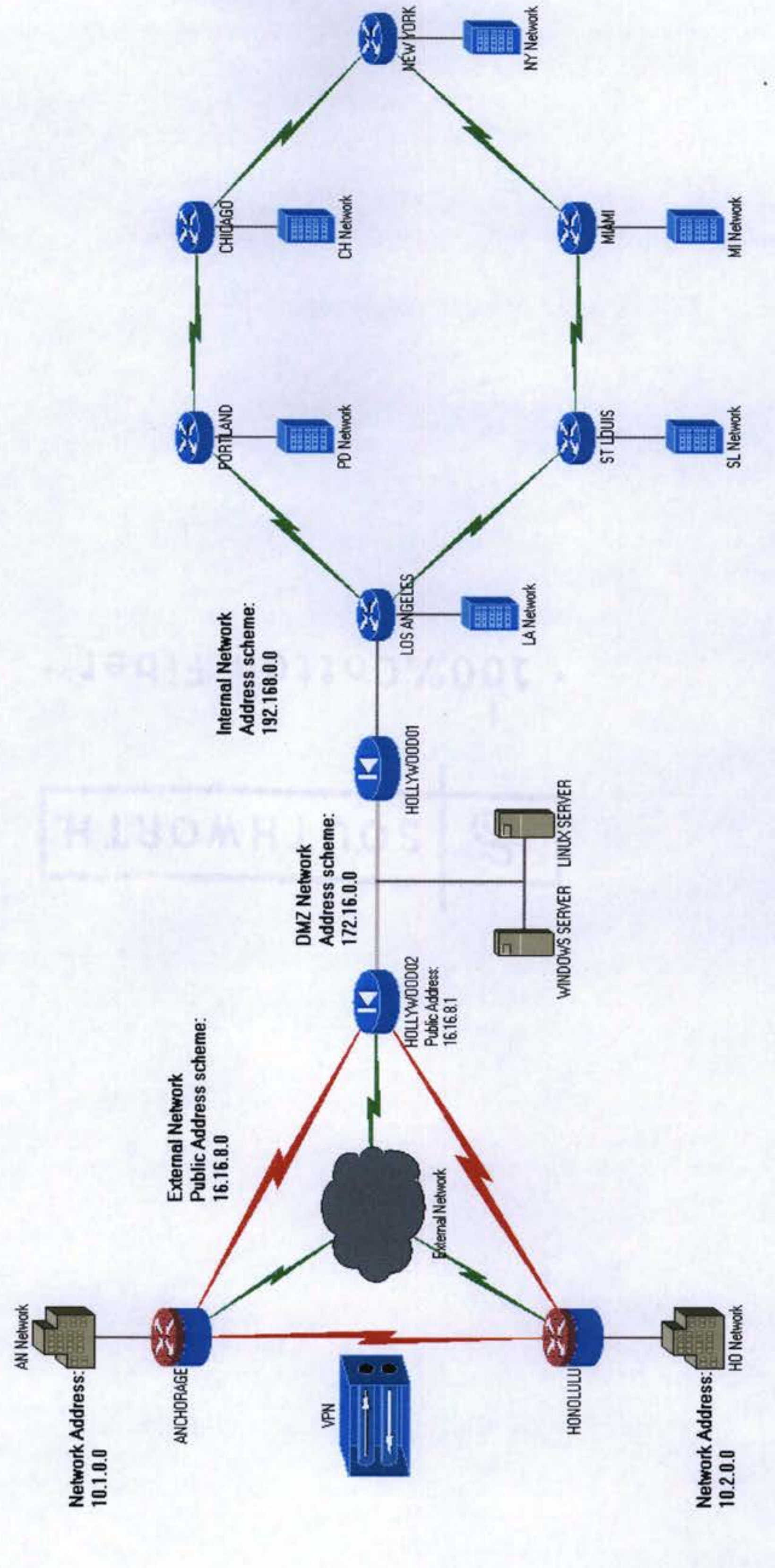

Figure 1. Existing Topology of the Telecommunications Laboratory (Zetino, 2011)

The devices are separated into three parts; the internal network, the perimeter network ("Demilitarized zone") and the external network.

The Internal Network consists of:

- Two Cisco 2500-series routers with two Ethernet/IEEE 802.3 interfaces and two serial network interface (Named ST_LOUIS and CHICAGO)
- Two Cisco 2500-series routers with one Ethernet/IEEE 802.3 interfaces and two serial network interface (Named MIAMI and NEW_YORK)
- Two Cisco 1900-series routers with eleven Gigabit Ethernet/IEEE 802.3 interfaces; two serial network interface; one terminal line; one VPN module; one Cisco Embedded AP (Named PORTLAND and LOS_ANGELES)

The perimeter network or demilitarized zone consists of:

- One Cisco Systems PIX-506E firewall with two Ethernet/IEEE 802.3 interfaces
- One Cisco Systems PIX-501 firewall with four Ethernet/IEEE 802.3 interfaces
- One Windows server
- One LINUX server

The external network consists of:

- Two Cisco 2801 routers with six FastEthernet interfaces; one Channelized T1/PRI port; two VPN modules; and eight voice resources
- One Dell PowerConnect 3424 switch with twenty-four Ethernet port with regular RJ-45 connector and four Gigabit Ethernet interfaces
- Two Cisco Systems IP phones 7961- series

In addition to these three sections, two Cisco Catalyst 1900/2820 switches are used for laboratory practices in Virtual Local Networks and Switch Port Security. One has twenty-seven fixed Ethernet/IEEE 802.3 interfaces (including AIU switch port on the back panel) while the other has fifteen fixed Ethernet/IEEE 802.3 interfaces (including AIU switch port on the back panel). Each of these switches has two 100BaseT switched ports for connecting to high speed servers, other switches or routers.

Each of these network devices are configured from the command prompt using the open source Putty software. The command line is used in order to get students familiar with configuration commands. Due to the fact that it is a laboratory environment, each network had a dedicated console machine. A console cable is used to connect the router to its console machine. The cable is an RJ-45 connector on one end (connects to console port on network device) and a DB-9 connector on the other end (connects to serial port the of console machine). All console machines have Windows 7 Enterprise Operating System installed.

Basic Requirements for an Online Laboratory

This research focuses on how to design online access to the Telecommunications laboratory at EIU School of Technology in order to achieve the learning outcomes of the course TEC 5313. It may also serve as the foundation for achieving online modality for other telecommunication courses. The online laboratory:

1. Should be designed to be interactive. Students should be able to follow step by step procedures and complete assignments with minimum help from the Instructor or Teaching Assistant.

2. Should be simple and easy to use. Students should focus on the task and not get frustrated from the cumbersome technology behind the design.

3. Should be engaging. Students should remain interested in the tasks at hand.

4. Should be designed to be collaborative as that students can perform practices as part of a team as in real-life scenarios.

5. Should be tailored to meet curriculum goals with quality; laboratory practices should be re-designed to achieve similar learning outcomes as traditional face-to-face experiments.

6. Should have a response time that mimics a real interaction with the equipment.

An online modality can be implemented in TEC 5313 using certain technologies bearing in mind the basic requirements for online laboratories above. Laboratory practices for TEC 5313; Networking and Advanced Data Telecommunications, which makes use of only hypothetical "internal network" of the laboratory shown in Figure 2. Current laboratory practices for TEC 5313; Networking and Advanced Data Telecommunications include:

i. Laboratory 1: Building a Local Area Network

ii. Laboratory 2: Knowing the Router OS parts I and II

iii. Laboratory 3: Static Routing Hands-on

iv. Laboratory 4: Troubleshooting LAN and WAN

v. Laboratory 5: Cabling: Building Straight-through, Crossed-over and Rolled-over Cables

vi. Laboratory 6: Dynamic Routing using EIGRP and OSPF

The laboratory practices listed above make use of equipment on the internal network (see Figure 2) and will remain the focus of this research. A more advanced course TEC 5353 "Network Security" makes use of the Demilitarized Zone and the External Network for laboratory practices in Network Address Translation (NAT) and Port Address Translation (PAT); Virtual Private Networks (VPN) and Voice over IP (VoIP). The internal network topology according to Zetino (2011) is represented Figure 2.

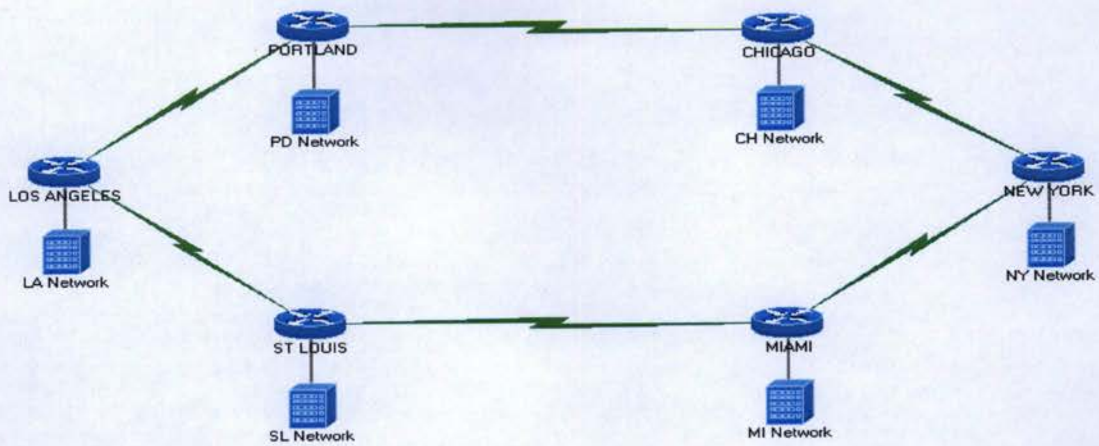

Figure 2. Ring Topology of Internal Network (Zetino, 2011)

Structure of the Online Laboratory

The online laboratory can be implemented in two phases each one requiring different levels of access and technology. Phase one uses the "Packet Tracer"® simulation software which may/may not require the user to log into the university network. The phase two combines the virtual laboratory and remote access to the physical laboratory using the same portal but requiring different level of accessibility and credentials.

Phase 1: Simulation Software - CISCO Packet Tracer

Although there are many network design simulators available today, such as ns-2, ns-3, OPNET and NetSim, Cisco's Packet Tracer is preferable for the Telecommunications Laboratory because most networking equipment in the telecommunication laboratory are CISCO® products. Cisco Systems has emerged as the leader in the networking equipment market. Packet Tracer is Cisco proprietary software and most commands that work on real CISCO devices are used in the Packet Tracer software. As a result, configurations can be saved, used on real equipment or saved for future references.

Different uinversities use different simulation software in teaching practical concepts by either purchasing or designing their own simulator. As an example, since 2004, University of Michigan has used OPNET simulation for an introductory computer networking course with positive feedback from the students (Guo, Xian, & Wang, 2007). Packet Tracer is available for free download on CISCO ® Systems Official website (www.cisco.com).

Mode of Operation

The student is required to register and create an account with CISCO before the software can be downloaded. Using carefully designed laboratory guides, the student can begin by designing the current topology of the Telecommunications laboratory at EIU in the simulated environment and begin configuring networking devices. The importance of easy-to-use laboratory guide cannot be overemphasized. It should describe the task and detail the steps involved so that the student can perform the practice with minimum supervision.

Figure 3 shows the first task the student is required to perform in order to replicate the existing network design. Since the simulation software allows configurations and network topology to be saved, each student can use a single topology throughout the course for all laboratory practices. There are two options for configuring the devices in Packet Tracer; using the Command Line Interface (CLI) as shown in Figure 4 or the Graphical User Interface (GUI). The CLI is used to ensure interaction with the equipment and also to ensure that students are accustomed to configuration commands.

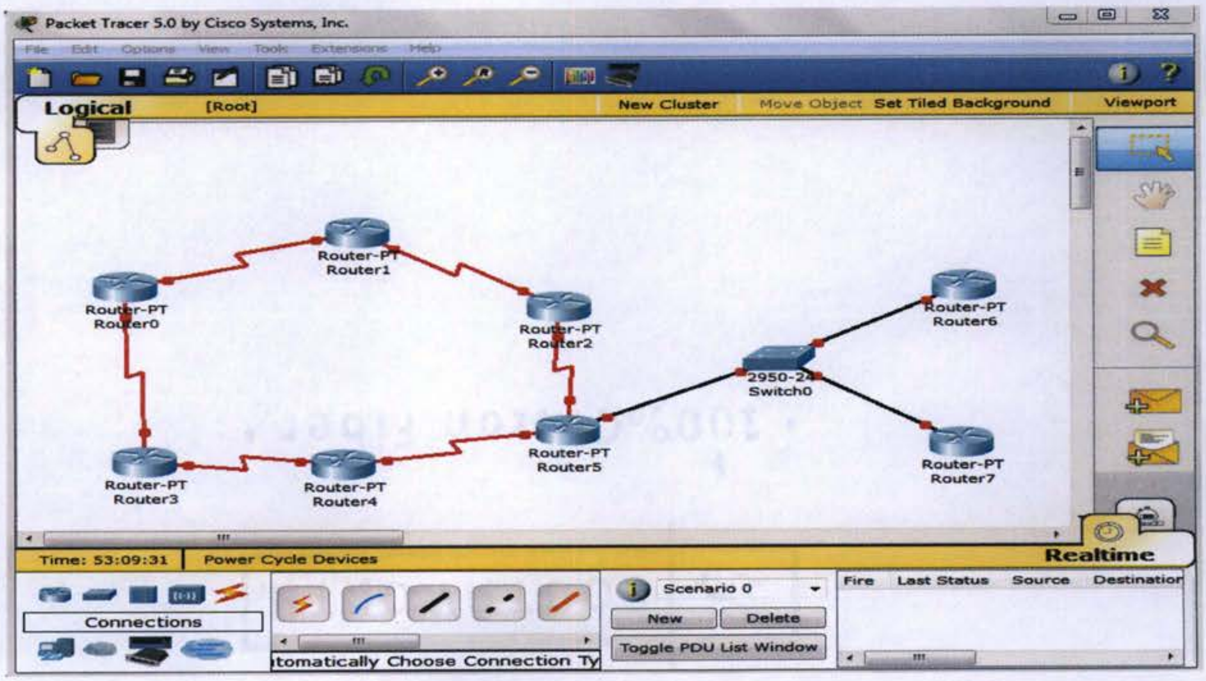

Figure 3. Existing Network Topology for Telecommunications Laboratory Using Packet Tracer

```
%LINK-5-CHANGED: Interface FastEthernet5/0, changed state to down
Router(config-if)#^Z
%SYS-5-CONFIG_I: Configured from console by console
Router#sh ip int brief
Interface              IP-Address      OK? Method Status                Protocol


FastEthernet0/0        192.168.1.2     YES manual up                    down

FastEthernet1/0        192.168.1.76    YES manual up                    down

Serial2/0              192.168.240.2   YES manual down                  down

Serial3/0              192.168.240.5   YES manual down                  down

FastEthernet4/0        unassigned      YES manual administratively down down

FastEthernet5/0        20.20.1.1       YES manual down                  down
Router#|
```

Figure 4. Sample CLI output

In the traditional laboratory, each student is assigned to a specific router for each practice. Using the Packet Tracer simulator® requires the student to perform the task entire alone and configure all devices on the network without the risk of damaging university equipment. Students who have installed the simulation software on their personal computers do not have to have internet access to carry out designated practices. The student can then perform the required task, save the network topology and configuration and submit online as an attachment to the instructor.

Although almost all the laboratory practices in TEC 5313 can be performed this way, only the basic practices will be designed in this research using Packet Tracer. Students will be required to complete other practices using the virtual laboratory or the remote laboratory in order to experience a more realistic interaction with the equipment. Although it is easy for the student to simply download and install the CISCO Packet Tracer ®software, EIU can obtain appropriate licenses and have the software available for download on the laboratory website. In addition to completing tasks and submitting the configuration online, the instructor can keep an archive of solution to individual practices. This can be made accessible online for the students to compare their solutions and for clarification.

Phase 2: Virtual Laboratory and Remote Access Laboratory

Figure 5. Block Diagram of the Online Laboratory

The online laboratory is represented in Figure 5. This block diagram is the basis for the design of the entire online laboratory. The remote user can access the authentication server over the internet. The authentication server also houses the virtual laboratory. The virtual laboratory to be implemented in this research is the SYBEX e-trainer CCNA Virtual Lab® and will be presented in detail in the following section. The remote user is shielded from the complexity of the system and only experiences the blocks presented in the Figure 5 as opposed to all complexity and layering of devices on the actual network. The remote user might have the choice of performing practices using the virtual laboratory software or to use the real laboratory equipment remotely.

System Design

The goal of this design is to allow students to perform networking experiments from remote locations with a high level of interaction with remote devices. In addition to the existing laboratory equipment, a router, a firewall, the distribution layer switches, and a virtual server must be added as shown in Figure 6. This equipment provides fast switching traffic, authentication services and restricted access to devices in the internal network in order to ensure that the remote user is able to perform only the expected experiments and nothing else. A Virtual Local Area Network (VLAN) is also used to provide a logical segmentation of traffic destined for the online laboratory from other university traffic for security purposes.

Major Design Elements

i. The External Router

- Analyzes incoming or outgoing packets and performs operations based on the information contained in the packet.
- Uses the Border Gateway Protocol (BGP) to make routing decisions between different Autonomous systems (AS).

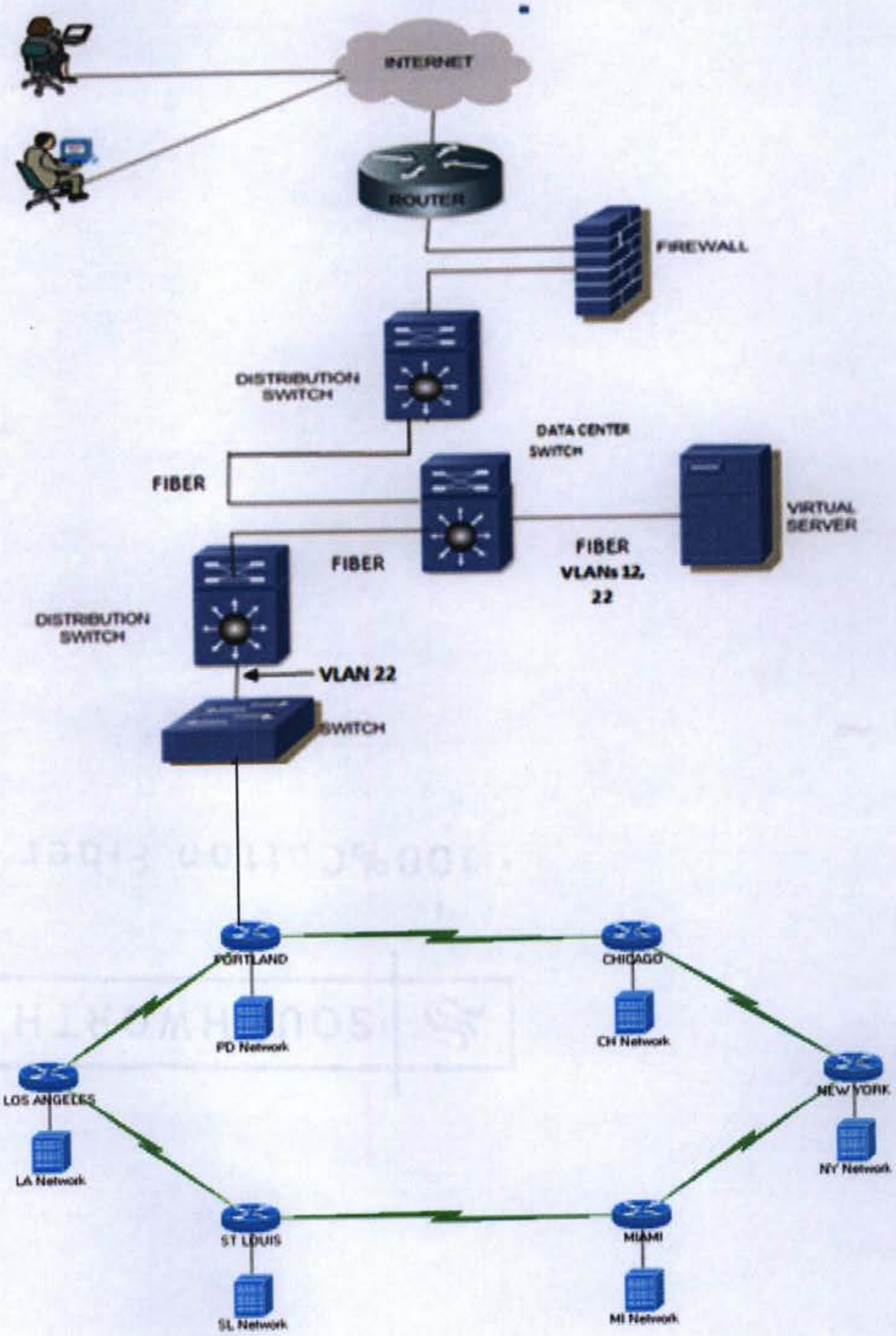

Figure 6. Design of the Internet Accessible Remote Laboratory

- Makes forwarding decisions by routing packets towards their destination.

- Routes packets to another interface or drop the packet. If the packet is outbound, it also determines to which service provider forward the packet.
- It is the first line of security for the network.
- The Firewall

The firewall defines the kind of traffic that is permitted in order to access the network from outside and the traffic allowed to leave from the internal network. Firewalls can be software or hardware based. In this design, a hardware-based firewall is implemented with redundancy to ensure security if the primary device fails. By using a set of rules configured within the firewall it is possible to restrict access to certain websites, domains and also filter content. The functions of the firewall in this design includes: restricting access to network devices form the internet, such as VPN connections; IP addresses filtering and domain names and packet filtering (Tyson, 200).

ii. The Distribution Layer Switches

Intelligent routing decisions are made at this layer of the hierarchical network, speed is an important consideration. The Distribution layer switches provide connections to other access layer switches in order to connect to the Telecommunications laboratory. The distribution layer switches in this design are very important because they collect data from all access layer switches across EIU campus, segments in order to direct traffic to the appropriate VLANs.

Where access to the internet is needed, the distribution layer switches forward traffic to the firewall and back to access layer switches from the internet. All this forwarding and filtering has to be done at very high speed. To this end, dedicated 10 Gigabits fiber optic cables connect the distribution switches to each other. All connections in and out of the distribution layer switches are trunk links making it possible to define the VLANs allowed to pass.

iii. The Virtual Server

The server in this design is a Virtual Machince (VM) that is hosted in ITS facility. The virtual server behaves as if its Operating System was installed on a separate machine with its own set of hardware, resources or programs. A virtual server is the same as a physical server only that it is software-based. The virtual server machine host has dual core processor, 8Gigabytes of RAM, 40 Gigabytes of storage and runs Windows Server 2012 OS. Being a VM makes it easier to upgrade the specifications of the server to meet up with class enrollment or other functions. This virtual server hosts the virtual laboratory software SYBEX e-trainer CCNA Virtual Lab® and also will manage user authentication to ensure that only authorized users are able to access the online laboratory.

Users will connect with the virtual server using Microsoft proprietary Remote Desktop Protocol (RDP) which provides access to remote devices on a computer network through GUI. RPD uses client-server architecture and is pre-installed on Windows OS. RDP uses TCP port 3389 for LAN connections while it uses TCP port 3390 for WAN connections. The remote user will be prompted for the log in credentials of the device he/she is attempting to access (Remote desktop protocol n.d.). The server has two network cards like a bastion host. One card belongs to public VLAN "A" the other card belongs to the private VLAN "B" of the Telecommunications laboratory. The server is responsible for routing user sessions between the two VLANs and directing laboratory traffic to VLAN "B". This will accomplish the isolation of the laboratory network in our facilities from the rest of the University network.

The Virtual Laboratory

It is important to state that the use of the virtual laboratory simulation software is SYBEX e-trainer CCNA virtual lab® offers a tangible level of flexibility. The simulation software can be upgraded at any time based on the needs of the curriculum with minimum effort. SYBEX e-trainer CCNA virtual lab is specialized laboratory software that provides an extensive hands-on experience with Cisco routers and switches which otherwise requires expensive networking equipment (Lammle & Tedder, 2001). It was designed as a training tool to prepare students for the Cisco Certified Network Associate

(CCNA) examination.

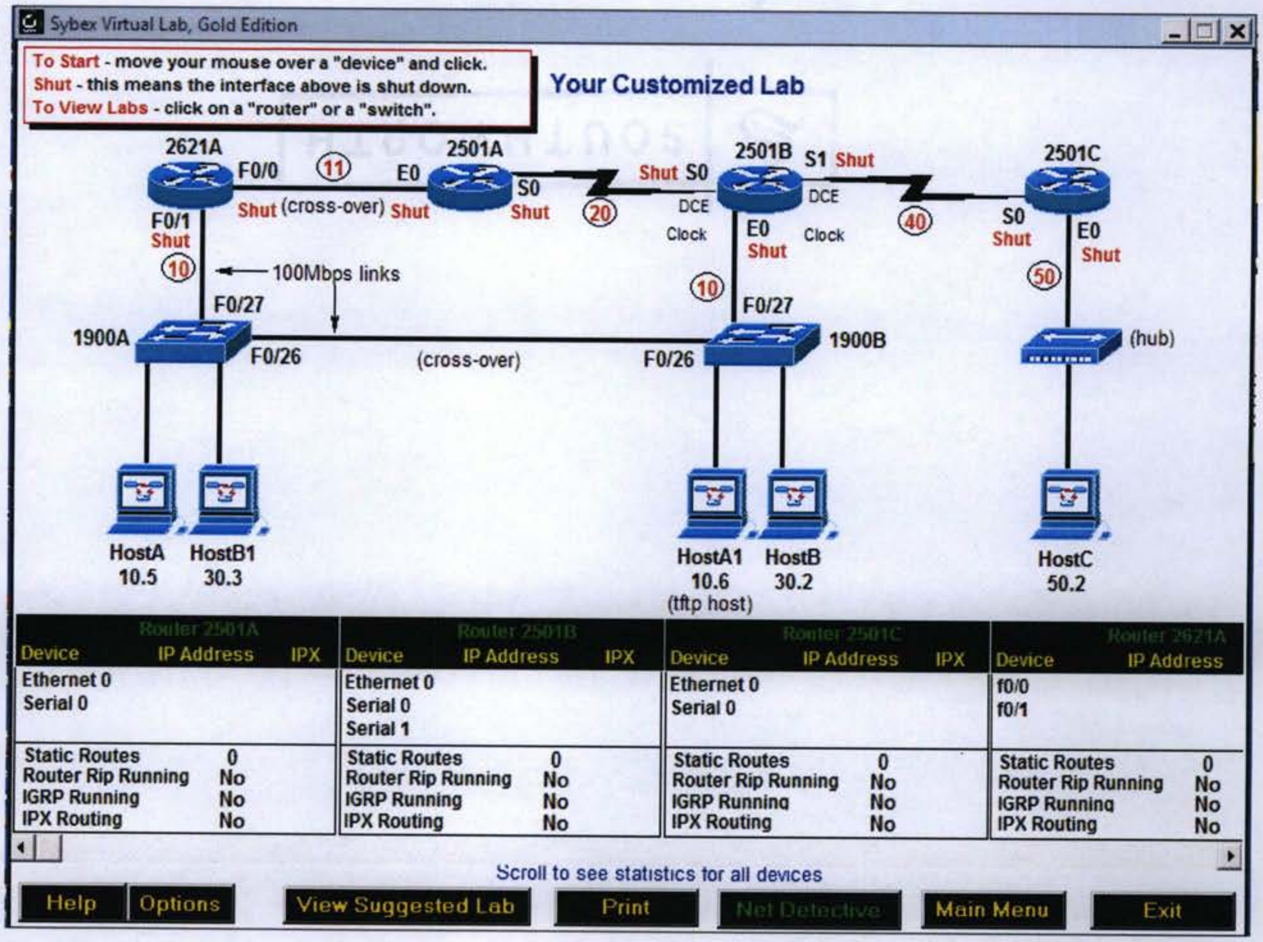

Figure 7. The Network Design of SYBEX E-Trainer CCNA Virtual Lab

The Virtual laboratory consists of four routers and two switches already arranged in a customized topology as shown in Figure 7. The virtual laboratory has already designed practices with step-by-step instructions. Practices in the package that correlate substantially to the curriculum at EIU includes

- Lab 4: Basic router configurations like IP addresses, hostnames, log in banners, password and how to save or view device configuration
- Lab 5: Configuring networks with default routes and static routes
- Lab 6: configuring VLANs

- Lab 9: Standard access lists and extended access lists

The SYBEX e-trainer CCNA virtual lab is interactive and easy use. The user is required to follow interactive steps and is able to observe the effect of each step on the overall network. The routers are configured from the CLI as shown in Figure 8. The CLI can be accessed by simply clicking on the device icon.

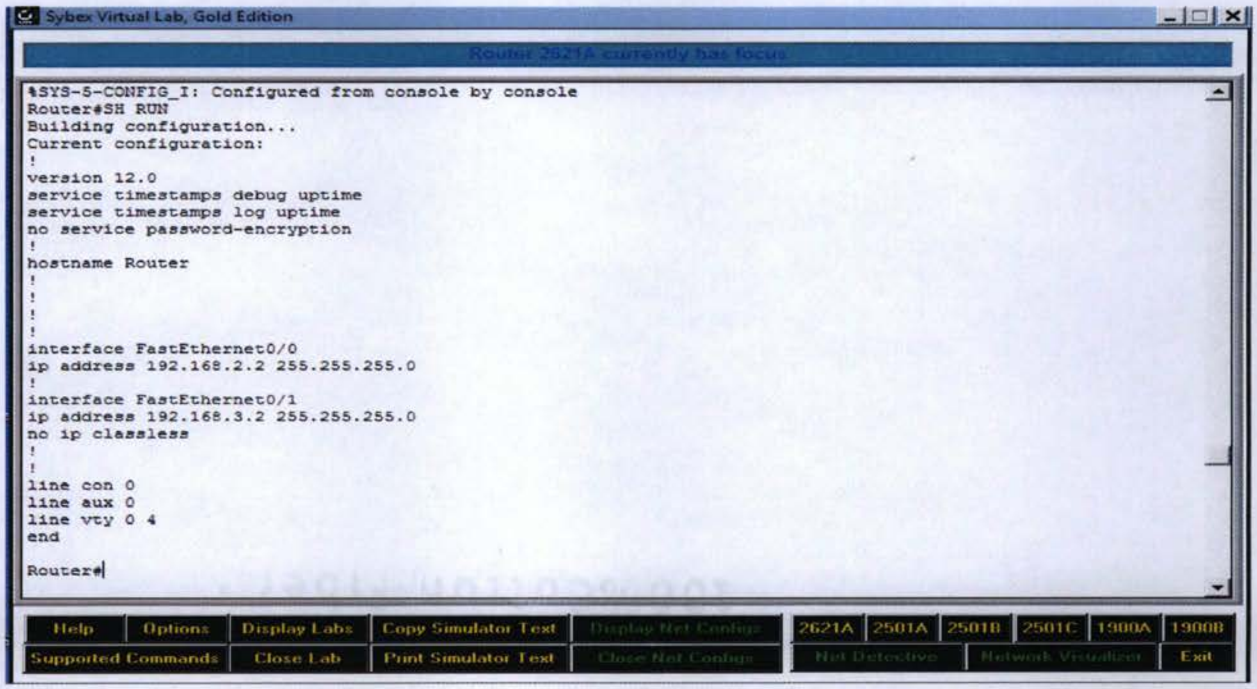

Figure 8. Output of Router 2621A from the CLI

An interesting advantage of the CCNA Virtual Lab is that the student is not relating with live equipment and cannot bring down a physical network. The SYBEX e-trainer CCNA virtual lab software allows configurations to be saved or printed by simply clicking on tabs on the screen. The SYBEX e-trainer CCNA virtual lab rolls back to the initial state for every new session. Students can use this service as they will the Packet Tracer simulator and submit their configuration as attachment to the instructor.

Remote Access to Physical Laboratory

The remote user is the client in the online laboratory using the internet as a medium of access. Every registered student is already part of the University's Active Directory (AD). Remote user connects to the server using RDP and is prompted for log in credentials. Student accounts are already part of the AD and will be used to authenticate remote users. This can be further developed so that the server authenticates remote users using the current enrollment for Networking and Advanced Data Telecommunications; TEC 5313. The virtual connection from the remote user terminates in the edge switch in Klehm hall which is physically wired to the hypothetical Cisco 1900 "PORTLAND" router. Due to the ring topology of the Telecommunications laboratory, the remote user can telnet to his/her assigned device on the network and perform appropriate practices.

Online laboratories are not self-sufficient to provide hands-on experience to the remote user. Students need to be provided with carefully designed laboratory guides, topology diagrams and wiring instructions in order to get full advantage of the facility. "At the least, by following the above strategies, we might reduce the current three Saturday meetings (8a.m. - 5p.m.) currently required in TEC 5313 in one semester to one morning meeting (8-noon) or to a one afternoon meeting (1-5 p.m.) in one semester. Contrary to previous visits which required most students be present at the same time, this short visit to the Laboratory might be scheduled upon each student convenience if this is implemented" (Dr. Chinchilla).

Chapter 4

Summary, Conclusions and Future Work

This research reports the basic layout and design of an internet accessible remote laboratory. It specifically focused on how laboratory practices for networking courses can be taught remotely in the School of Technology at Eastern Illinois University using existing laboratory equipment and the university's network infrastructure. This research also provides details of the technologies and basic equipment required to shield the user from the complexities of the design while ensuring adequate security and no damage to EIU due to security breach or experimental errors. To this end, traffic destined for the remote laboratory is isolated on a separate VLAN to force traffic from remote users to the remote laboratory with no option of accessing the University's networking devices. Using the design presented in this research as a foundation, similar remote access can be provided to other courses/laboratories in the School of Technology as well as other programs at EIU.

When providing access to an isolated laboratory from remote locations via the EIU network infrastructure, it is mandatory to work with the university network managers. In the case of EIU, the Information Technology Services (ITS) Department manages the entire university's network. Collaboration with ITS helped to ensure compliance with EIU network policies and to ensure that the university's network is not compromised in the process of granting remote privileges to online laboratory users. Also, all the components in the design that are transparent to the remote user are hosted and managed by the same department. As a result, the network equipment as well as the virtual server will be properly managed and kept up-to-date with little effort on the part of the instructor or the TA.

To sum up the phases of complexity and options presented in this research, the Packet Tracer simulation software allows the student to learn how to configure networking equipment from scratch at their own pace and test various "what-if" scenarios without fear of damage to laboratory equipment while internet access is not even necessary. The virtual laboratory functions like the simulator but it required internet access and it gives the student the feel of an actual laboratory. Lastly, the remote laboratory makes it possible for students to perform experiments remotely at their own pace and convenience.

This research has exhaustively investigated the present state of development of the remotely accessible telecommunications laboratory in education and training industry. As opposed to the development of remote laboratories in Electrical Engineering, little has been done in Computer Engineering and Networking to cater to the need of distant learners. Many published websites and articles on remotely accessible networking laboratories only exist in documentation and real implementations are still in their early developmental stages. In the course of this research, a video conference session was conducted between the author, Dr Rigoberto Chinchilla and Dr. Abul Azad, Professor at Northern Illinois University (NIU). Dr Azad developed a functional Internet accessible remote laboratory used for multiple courses at NIU and has also published a book on internet accessible remote laboratories. Also, there was e-mail correspondence with Sumit Dutta, a former student at the University of Illinois in Urbana-Champaign who worked on a Remote Lab Web Services project.

Conclusion

The main purpose of this research was to exhaustively investigate the possibility of developing an internet accessible remote laboratory focusing initially on the networking curriculum at Eastern Illinois University. This has been proven true and the design has been developed to serve as a foundation for future remote laboratories at EIU especially in the School of Technology.

The design overcomes the limitation of traditional laboratories, which includes lack of remote access, time limitation, space limitation and possible damage to equipment. When fully implemented, the remote laboratory has the potential to increase the level of accessibility and availability of the Telecommunications laboratory at Eastern Illinois University so that at least one graduate level, networking course can be taught in an online modality with the physical meetings reduced to the minimum.

In its current developmental state, online laboratories may have the capability to completely replace hands-on physical interaction with real equipment. Online laboratories are the next-best option to a traditional laboratory and can be strategically designed to provide a level of satisfaction that is close to reality. Most institutions studied in this research use only one of the three methods presented here for remote experiments. However, a hybrid approach may be more appropriate in order to achieve better learning outcome, especially in students with very little experience in configuring telecommunication devices.

Future Work

The design of the internet accessible remote laboratory has been presented and investigated in this research. This research is the first of its kind at EIU. The next step is the implementation of the design already presented. There is a possibility that the actual implementation may deviate slightly in the course of implementation. The implementation should include, but is not limited to:

- Adequate documentation of further studies and changes should be in order for the progression to be available for similar researchers with similar interests.
- The design of a highly interactive graphical user interface (GUI) for the two phases presented in this research to guide the remote user through the online laboratory with minimum difficulty.
- Re-design of current laboratory guides/manuals to suit the online laboratory since current laboratory guides were designed for the student to be physically present. A typical example is represented in Appendix C; a laboratory guide prepared for VLAN practices using the Packet Tracer simulator. The manuals should be strategically designed so that the online learner can carry out practices with little or no help.
- Creation of media files, including audio or video to exemplify the process of carrying out Physical Cabling practice cannot be replicated in the online environment. Video is more likely to increase the student's understanding.

Appendix D presents the result of the survey conducted on students of AET 2523 "Routing and Switching Fundamentals" Fall 2012 semester at EIU to evaluate their satisfaction on the use of Packet Tracer software, the sample size was little, does not evaluate the use of virtual laboratory and remote access to physical equipment. Future studies can be carried out with a more random population/sample to evaluate student satisfaction on the use of the entire online laboratory in order to tune the laboratory to meet the need of its customers; the students.

References

Academic OPNET research and educational projects. (n.d.). Retrieved from University Project: http://www.eecs.umich.edu/dco/docs/ecad/opnet_usage.html

Albon, S., & Cancilla, D. (2012). Online laboratory education: Principles and practices of the integrated laboratory network.

Boson (2008). NetSim: Network Simulator Software. Retrieved from http://www.boson.com/AboutNetSim.html

Box, J. F. (1987). Guinness, Gosset, Fisher, and small samples. *Statistical Science, 2*, pp. 45-52. Retrieved from http://www2.fiu.edu/~blissl/GuinessGossetFisher.pdf

Brown, S., & Lahoud, H. (2005). An examination of innovative online lab technology. *Proceedings of the 2005 ACM Information Technology Education Conference,* (p. 65- 70). Newark, NJ.

Chaney, B.H., & Eddy, J.M., et al, (2007), Development of an instrument to assess student opinions of the quality of distance education courses. *The American Journal of Distance Education,* Vol. 21(3), pp 145-164.

Chorafas, D. (1965). *Systems and Simulation.* New York: Academic Press.

Cisco packet tracer. (n.d.). Retrieved November 19, 2012, from Cisco: http://www.cisco.com/web/learning/netacad/course_catalog/PacketTracer.html

Cooney, E., & Shiver, A. (2001). Remte control of a robot using LABVIEW and world wide web. *ASEE Annual Conference & Exposition* . Albuquerque.

Cooper, M., Donnelly, A., & Ferreira, J. (2002). Remote controlled experiments for teaching over the internet: A comparison of apporaches developed in the PEARL project. *The ASCILITE Conference* (pp. M2D.1-M2D.9). Auckland: ASCILITE.

Deniz, D. Z., Bulancak, A., & Ozcan, G. (2003). A novel approach to remote laboratories. *33rd Annual Frontiers in Education*, (pp. T3E8-12).

Erwin. (2011, May 24). *What is OPNET?* Retrieved from Qwhatis.com: http://www.qwhatis.com/what-is-opnet/

EUROSTAT. (n.d.). Retrieved February 27, 2013, from http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/themes

Fapeeler. (2008, July 8). *Virtual computing lab: How it works*. Retrieved from NC state University: http://vcl.ncsu.edu/help/general-information/how-it-works

Frezzo, D., Behrens, J., Misleyy, R., West, P., & DiCerbo, K. (2009). Psychometric andvEvidentiary approaches to simulation assessment in packet tracer software. *Fifth International Conference on Networking and Services.* Valencia.

Gregg, M. (2008). Build your own security lab: A field guide for network testing. Indianapolis, IN: Wiley Publishing, Inc.

Goldsman, D., Nance, R. E., & Wilson, J. R. (2010, December 7). A brief history of simulation revisited. Retrieved January 19, 2013, from www.ise.ncsu.edu/jwilson/simhist10.pdf

Guo, J., Xian, W., & Wang, S. (2007). Reinforce networking theory with OPNET simulation. *Journal of Information Technology Education, 6.* Retrieved November 19, 2012, from http://www.jite.org/documents/Vol6/JITEv6p215-226Guo236.pdf

Gurocak, H. (2000). Initial steps towards distance delivery of a manufacturing automation laboratory course by combining the internet and interactive TV system. *2000 ASEE Annual Conference & exposition.* St Louis.

Hashemian, R., & Pearson, T. (2012). Teaching hardware design with online laboratories. In A. Azad, M. Auer, & J. Harward, *Internet accessible remote laboratories: Scalable E-Learning tools for enigineering and science disciplines* (pp. 18-37). Hashey: Engineering Science reference.

Huang, C. (2004). Vitural labs: E-learning for tomorrow. *PLoS Biology*, 0734.

Iqbal, M., Kousar, N., & Ajmal, M. (2011). Collaborative learning: Myth for distance learning? *International Journal of Academic Research, 3*(4), 605-608.

Khan, A.W. (2003). *Shaping the future with knowledge: Empowerment through education and training*. Gazipur: Convocation address at the Bangladesh Open University.

Lahoud, H. A., & Krichen, J. P. (2010). Networking labs in the online environment: Indicators of success. *Journal of Technology Studies , 36* (2), 31-40.

Lammle, T., & Tedder, W. (2001). *CCNA virtual lab.* Alameda: Sybex.

Lawson, E. A., & Stackpole, W. (2006). Does a virtual networking laboratory result in similar student achievement and satisfaction? *Proceedings of the 2006 ACM Information Technology Education Conference,* (p. 105-114). Minneapolis, Minnesota.

Lloret, J., Jimenez, J., Diaz, J., & Lloret, G. (2008). A remote network laboratory to improve university classes. *5th WSEAS / IASME International Conference on Engineering Education.* Heraklion, Greece.

Ma, J., & Nickerson, J. V. (2006). Hands-on, simulated, and remote laboratories: A comparative literature review *ACM Computing Surveys,* Vol. 38. New York, NY.

Maj, S. P., & Veal, D. (2010, December 10). Low cost, pedagogically enhanced, remote access,laboratory based instruction for developing countries. *Scientific Research and Essays* , *6*(1), 168-174.

Mwikirize, C., Tumusiime, A., Musasizi, P., Tickdri-Togboa, S., Jiwaji, A., Nombo, J., . . . Mwambela, A. (2012). Collaborative developments and utilizatin of iLabs in East Africa. In A. Azad, M. Auer, & J. Harward, *Internet accessible relote labratories: Scalable e-learning tools for engineering and science disciplines* (pp. 108-122). Hershey: Engineering Science Reference.

NetSim Network Simulator. (2013). Retrieved from Boson: http://www.boson.com/netsim-cisco-network-simulator

ns (simulator). (2013, February 26). Retrieved from wikipedia: http://en.wikipedia.org/wiki/Ns_(simulator)

ns-3. (n.d.). Retrieved 02 05, 2013, from http://www.nsnam.org/overview/what-is-ns-3/

Ozvoldova, M., & Schauer, F. (2012). Remote experiments in freshman engineering education by integrated e-learning.

Rajendran, L., Veilumuthu, R., & J, D. (2010). A study on the effectiveness of vitual lab in E-learning. *International Journal on Science and Engineering, 02*(06), 2173-2175.

Rojko, A., Ziircher, T., Hercog, D., & Stebler, R. (2012). Implementation o Remote Laboratories for industrial education. In A. Azad, m. Auer, & J. Harward, *Internet* *accessible remote laboratories: scalable e-learning tools for enginnering and science disciplines* (pp. 84-107). Hershey: Engineering Science Reference.

Rojko, A., Zurcher, T., Hercog, D., & Stebler, R. (2011). Implementation of remote laboratories for industrial education.

Rorabaugh, C. B. (2004). *Simulating wireless communication systems.* New Jersey: Prentice Hall.

School of technology. (n.d.). Retrieved October 5, 2012, from Eastern Illinois University: http://www.eiu.edu/tech/

Sarkar, N. (2006). Teaching computer networking fundamentals using practical laboratory exercises. *IEEE Transactions on Education*, 49(2), 285-291

Sivakumar, S. C. (2005, November 1). A web-based remote interactive laboratory for internetworking education. *IEEE transactions on Education, 48*(4), 586.

Sloan, J. (2002). A remotely accessible networking laboratory. The Journal of Computing in Small Colleges, v.18 n.2, p.215-222, December 2002.

Sloan, J. & Schlindwein, C. (2004). TCP/IP laboratory exercises for use with a remotely accessible networking laboratory, The Journal of Computing in Small Colleges, v.19 n.3, p.68-78, January 2004.

Steve, L., Willis, M., & Wei, Z. (2001). Virtual networing laboratory (VNL): Its concepts and implementation. *American society for engineering education annual conference and exposition.* Albuquerque.

Tang, Y., Draper, T., & Xu, Z. (2008). Hyperlab: Towards building a hybridized and adaptive remote computer networking laboratory. Retrieved February 19, 2012 from http://www.itk.ilstu.edu/faculty/ytang/TR-Hyperla-ytang.pdf

Yoo, S., & Horis, S. (2004, March). Remote access internetworking laboratory. *ACM SIGCSE Bulletin*, *36* (1).

You, Y. (2012). A LabVIEW-based remote laboratory: Architecture and implementation. In A. K. Azad, M. E. Auer, & V. J. Harward, *Internet accessible remote laboratories: Scalable E-Learning tools for engineering and science discipline* (pp. 1-17). Hershey: Engineering Science Reference.

Zetino, J. (2011). *Design and evalution of laboratory practices for a comprehensive networking curicullum* (Master's thesis). Eastern Illinois University.

Appendices

1. Appendix A: Definition of Terms
2. Appendix B: Survey on Packet Tracer Simulation Software
3. Appendix C: Manual for VLANs and Router-on-a-Stick practice using Packet Tracer
4. Appendix D: Email Correspondence with Sumit Dutta

Appendix A

Definition of Terms

Router: *A router is device that operates at the network layer of the OSI model. It helps to control broadcasts and collision. Routers link multiple Local Area Networks together or with other Wide Area Network or the internet.*

Switch: *A switch is used to join multiple computers on a Local Area Network. A switch has more intelligence than a hub and is able reduce collisions on the LAN*

Firewall: *A firewall is software or hardware that filters what comes into or leaves a network and either allows it to pass or blocks it based on the firewall setting.*

Authentication: *The process of determining whether a user is who he/she claims to be.*

Bastion host: *It is a special computer that resides in the DMZ and is configured to withstand attacks. It acts as a proxy and mostly houses the services and applications that outsiders need to have access to.*

Demilitarized zone (DMZ): *This is referred as the perimeter network; it acts as bridge between a LAN and the internet or external network. It adds additional layer of security*

Virtual server: *A conceptual server that does not exist physically but is hosted as part of a larger physical server.*

Remote Desktop Protocol (RDP): *This is a Microsoft proprietary protocol that allows a remote device to access the desktop of another remote device over a connection.*

Virtual Local Area Network (VLAN): *This is separate broadcast domain created on switches to segment a LAN. Traffic from one VLAN does not flow to devices in another VLAN expect such feature is deliberately enabled.*

Command Line interface (CLI): *This is similar to the MS-DOS prompt in computers; it allows the user to interact with the operating system of a device. Once the user types the command, the communication equipment acts on the command as gives a new prompt for the user to enter the next command.*

NAT/PAT: *Network address translation/Port Address Translation is used by network devices like routers and firewalls to convert a private internal IP address (or group) to a public IP address for economic reasons, non-availability of enough public IP addresses or for security reasons*

Appendix B

Survey on Packet Tracer Simulation Software

The survey reported below was conducted on students of AET 2523 "Routing and Switching Fundamentals" Fall 2012 semester at EIU. The class used the physical routers and switches for their laboratory sessions as well as the Packet Tracer software. The intent here was to obtain feedback on their level satisfaction, ease of use and learning outcome in the two methods used. The survey was anonymous and asked very basic questions listed below.

1. How will you describe your experience with real networking equipment (Routers, switches, cables)?
2. How will you describe your experience with Cisco Packet Tracer simulator?
3. Which of the two will you prefer?
4. Why did you make this choice?
5. Will you prefer to do your laboratory practices remote from your dormitories and other locations? Why?
6. Will you rather use the physical equipment? Why?
7. If you will like to do your laboratory sessions remotely, what will you require of the remote laboratory based on options listed below
    - Ease of use
    - Simplicity
    - Speed
    - Interactive prompts
    - Ability to still work in teams

- Ability to still use the physical laboratory

8. Any other comment or suggestions for remote/online laboratory

The responses received from the survey is discussed below

1. To the questions "How will you describe your experience with real networking equipment (Routers, switches, cables)", responses ranged from "it is complicated" to "very slim" while others stated that they had little experience programming their home devices for internet connectivity
2. To the question "How will you describe your experience with Cisco Packet Tracer simulator", responses included the fact that it was easy to use, it helped to understand the material much better, it allowed each student to look at the entire network and it was interesting to use
3. To the question "which of the two will you prefer" the responses varied. 3 out of 5 will rather use the simulation software while remaining 2 will prefer the real equipment.
4. To the question "why did you make this choice", the 3 students who prefer the simulator stated reason such as ease of use; it is more educational, ability to create more scenarios and no fear of damage to the real equipment. The 2 students who prefer the real equipment such as being able to touch a physical device and better hands-on experience.
5. To the question "Will you prefer to do your laboratory practices remote from your dormitories and other locations and why", only 1 student will really want to do remote laboratory; other 4 students will still prefer to come to the classroom.

6. To the question "Will you rather use the physical equipment and why", majority of the class prefer the physical equipment. Only 1 student will prefer the simulator because the physical equipment is difficult to understand.
7. Each student's requirement for a remote laboratory, students chose options like ease of use, simplicity, interactive prompts and ability to still visit the physical laboratory
8. Comments and suggestions included
    - Ability to still meet with professor if there is problem
    - Professor should discuss the remote laboratory in class with students
    - The remote laboratory should not get complicated and simple

Appendix C

Manual for VLANs and Router-on-a-Stick practice using Packet Tracer

This laboratory guide is designed to provide step-by-step instruction to guide students on how to use the Cisco Packet Tracer software to learn the concept of creating VLANs as well as enabling inter-VLAN routing; a technique commonly called Router-on-a-Stick. It is assumed that the Student has already installed the software on his/her PC or is using one of the PCs in the lab. It is also assumed that the student has attended and participated in classroom or reading sessions on VLANs

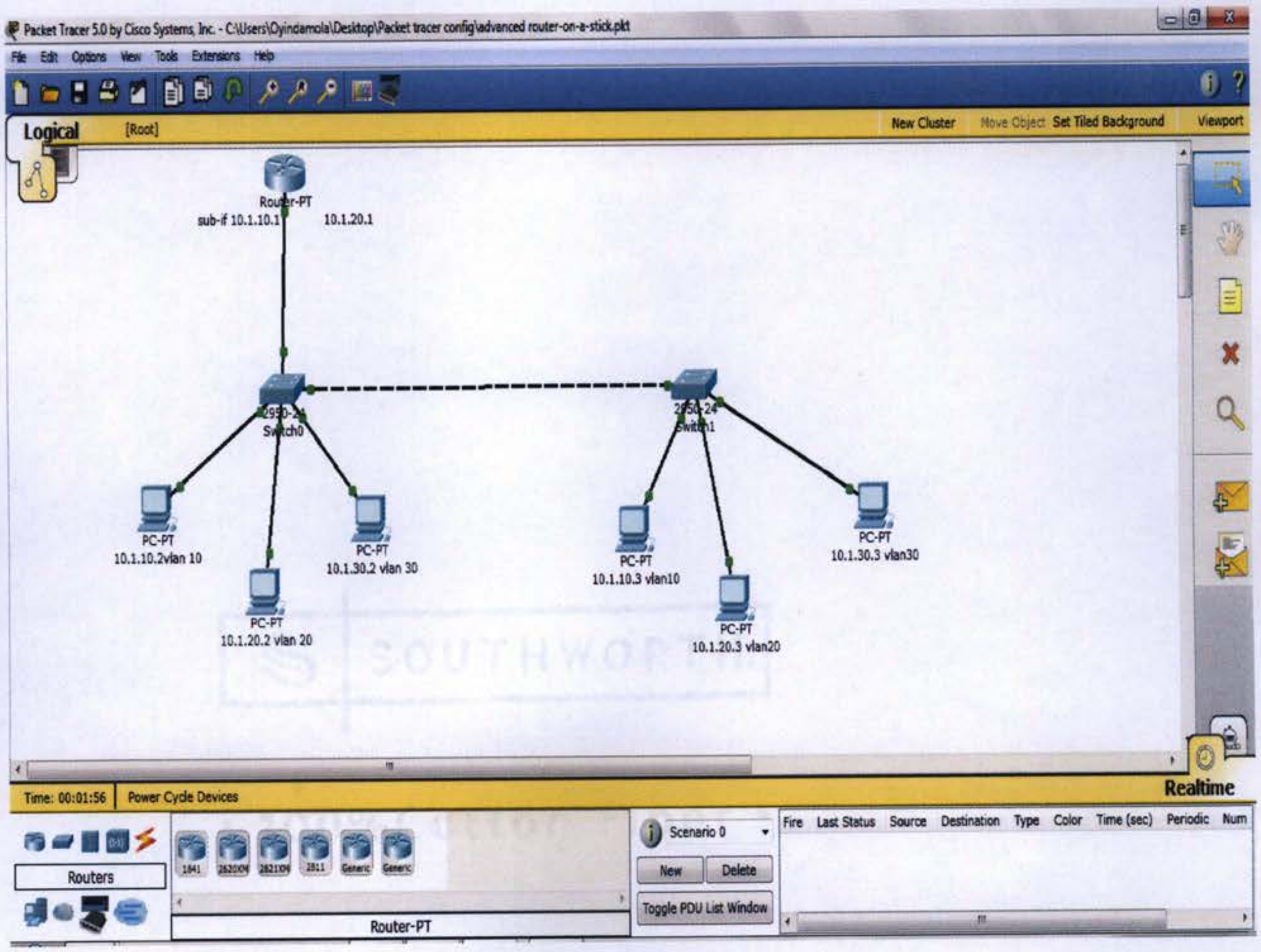

Figure 9. Configuring VLAN Using Packet Tracer Simulator

Part I: CREATING VLANS FROM CLI

Step 1: Design the network diagram provided using the Packet Tracer 5.0 simulation software on your console machine desktop. The GA should do a short demo of how to use the software

All devices are located on the low left hand corner of the screen. Click on the icon once and click your workspace once or simply drag-and-drop the device you want.

- click on switches and pick the first one (2950-24)
- Repeat the step above so that you have 2 switches in you work area
- Click on connections and pick a crossover cable to connect the two switches. Use fastethernet0/4 on both switches for consistency (you can always use any interface)
- Now click on end devices and pick a generic PC.
- Repeat the step above until you have 3 PCs for each switch as shown in your network diagram
- Click on connections and use a straight-through cable to connect the PCs to fastethernet0/1, 0/2 and 0/3 on each switch to fastethernet port of each PC
- Click on routers and pick the generic router
- Click on connections and pick a straight-through cable to connect the router (fastethernet0/0) to a switch (fastethernet 0/5) as shown in your network diagram

Step 2: Configure Trunk Link between Both Switches

Both switches are connected on fastethernet0/4. To configure this link as a trunk, enter the following commands on both switches

Switch(config)#interface fastethernet0/4

Switch(config)#switchport mode trunk

Switch(config)#exit

<u>Step 3</u>: Configure the switches for Vlan

Create Vlan 10, 20 and 30 on switch0

a) Click on switch0 and on the top left corner of the screen click on CLI. You are now in the command line interface of the switch.

Type the command: Switch# show Vlan

How many vans exist on the switch by default?

____

Which ports are in this vlan?____

b) In global configuration mode, type the following commands

Switch(config)# vlan 10

Switch(config-vlan)#name accounting

Switch(config-vlan)#exit

These commands create vlan 10 and give it the name "accounting".

Switch(config)#interface fastEthernet 0/1

Switch(config-if)#switchport mode access

Switch(config-if)#switchport access vlan 10

Switch(config-if)#exit

These commands configures fasthernet0/1 as an access port and assigns it to vlan10

c) Using the steps in b) above, create vlan 20, give it the name 'sales' and assign fastethernet0/2 to vlan 20

d) Using the steps in b) above, create vlan 30, give it the name 'engineering' and assign fastethernet0/3 to vlan 30

Use the command show vlan to view the vlans you created

How many vlans exist on the switch now?

____

Which ports are in these vlans?

____

____

____

Step 4: Create Vlan 10, 20 and 30 on switch1

Repeat steps a) to e) on the second switch to create vlan 10,20,30 and assign interfaces fastethernet0/1, 0/2 and 0/3 respectively

Step 5: Assign IP address to hosts

SWITCH0		
Vlan 10	Vlan 20	Vlan 30
Accounting	Sales	Engineering
10.1.10.2/24	10.1.20.2/24	10.1.30.2/24
SWITCH1		
Vlan 10	Vlan 20	Vlan 30
Accounting	Sales	Engineering
10.1.10.3/24	10.1.20.3/24	10.1.30.3/24

Now, assign IP address to all the hosts, use the table above and the network diagram provided. To do this,

-click on the host

- click on desktop

-click on IP configuration

-type the appropriate IP address and subnet mask. Leave the default gateway blank

Step 6: Vlan verification

Using the ping tool, can you ping hosts in the same vlan?________________________________

Ping a host in another vlan, was the ping successful?____________________________________

Why?____

______

Instructor signature____________________________________

PART II Router-On-A-Stick

Do not proceed to this section until part II works and is approved by instructor

Router-on-a-stick is a terminology used to describe inter-VLAN routing. After this section, you should be able to ping hosts in different VLANs. You will configure the router and the switch connected to it.

Step 1: Configure a trunk link between the switch and the router

Switch(config)# interface fa0/5

Switch(config-if)#switchport mode trunk

Switch(config-if)#exit

Step 2: Activate the router interface

Router(config)#interface fa0/0

Router(config-if)#no shutdown

Router(config-if)#exit

Step 3: Create two router sub-interfaces for vlan 10 and vlan 20 to communicate

Router(config)#interface fa0/0.1 | this command creates a sub-interface

Router(config-subif)#encapsulation dot1q 10 | links the sub-interface to vlan 10

Router(config-subif)#ip address 10.1.10.1 255.255.255.0

Router(config-subif)#exit

Router(config)# interface fa0/0.2 | command creates a sub-interface

Router(config-subif)#encapsulation dot1Q 20 |links the sub-interface to vlan 20

Router(config-subif)#ip address 10.1.20.1 255.255.255.0

Router(config-subif)#exit

Step 4: configure default gateway on your hosts

Go back to your network diagram and put the default gateway on your hosts as follows

Hosts in vlan 10, default gateway = 10.1.10.1

Hosts in vlan 20, default gateway = 10.1.20.1

Step 5: Verification

From hosts in vlan 10, try to ping hosts in vlan 20

Was the ping success? -

____

Explain the initial output (why did the request time out at

first?)_____________________

____

_____

____

_____

This is the achievement of inter-vlan routing using a single interface of a router!

From hosts in vlan 10 or 20, ping hosts in vlan 30

Was the ping successful? -

____

Why?____

_____

Appendix D

Email Correspondence with Sumit Dutta

Below is the e-mail correspondence with Sumit Dutta, a former undergraduate student at UIUC. He previously conducted a project to add practical content to an entirely theoretical course at UIUC with laboratory practice that can be conducted in the online environment. Basically, his work allows remote students to watch electrical practices being performed onsite at UIUC and also take measurements.

From: "Sumit Dutta" <sumitd@MIT.EDU>

To: "Oyindamola O Idowu" <ooidowu@eiu.edu>

Sent: Thursday, January 24, 2013 12:51:31 PM

Subject: RE: Important: from Easter Illinois University

Dear Oyindamola,

I appreciate your interest in the Remote Lab Web Services project at UIUC. I am now a graduate student at MIT, so although we cannot meet in person I can still share my insights on my Remote Lab with you.

I worked on the Remote Lab project under Professor Eric Pop (epop@illinois.edu), who is at UIUC. The major reason I created the Remote Lab was to add a small lab component to a heavily theoretical class, ECE 440. It was designed to encourage students with a glimpse of real-world electrical tests for transistors, and in no way would replace our lab class ECE 444. Nevertheless, your situation is still a valid use case for the Remote Lab since students can still get data collection experience online.

If you have a recent version of LabVIEW at EIU, you may find parts of my Remote Lab code useful for your purpose. The LabVIEW code must run on a PC with a known hostname or IP address (so that you can access it with a URL) and should have a measurement instrument connected to it by GPIB. If you do not have the same Keithley 26xx instrument we used you will have to modify the instrument-specific code. I hope this gives you a clear idea about the Remote Lab code, and feel free to ask questions.

Please visit http://remotelab.sourceforge.net/ to download the code that I have open sourced.

Sincerely,

Sumit Dutta

From: Oyindamola O Idowu [ooidowu@eiu.edu]

Sent: Thursday, January 24, 2013 12:30 PM

To: sdutta3@illinois.edu

Subject: Important: from Easter Illinois University

Dear Sumit Dutta,

I am Oyindamola Idowu, am a graduate student/ GA at the School of Technology, Eastern Illinois University, Charleston. I am the GA for Telecommunications lab and my supervisor is Dr. Rigoberto Chinchilla. This semester, we are researching the possibility of moving some (if not all) of our laboratory practices from face-to-face to online and I came across your work.

We (my professor and I) will like for you to share from the experience you gained while working on "Remote Lab Web Services Using LabVIEW" and research how we can apply this to our specific needs at EIU.

If this is an idea that you welcome, we will like to come over to Champaign and meet with you in person and maybe see the facilities you have on ground too. We will like for you to give us an appointment for any convenient day in the month of February.

Thank you for your attention

Oyindamola Idowu